



# SAGE III

## Stratospheric Aerosol and Gas Experiment

An Earth Science Mission on the International Space Station

Feedback from ESD Senior Review 2023  
& Plans for the Next 3 Years

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# Mission Highlights



- The recently released v5.3 products utilize Disturbance Monitoring Package (DMP) data to refine instrument pointing
  - Establishes < 10% of observations impacted by ISS mechanical disturbances exceeding requirements
  - Reduces measurement uncertainty at all altitudes – largest improvement at high altitude
- Ozone used in trend studies
- Chemistry of smoke in stratosphere
- Aerosol used to calibrate current scattering methods
- Vibrant internship program with ~5 NASA interns/yr



# Important planned activities for the next 3-yrs

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- **Supporting the 2026 WMO International Ozone Assessment**
  - Release improved Solar and Lunar products (CY2024)/ support interpretation of data details
- **Review Level 1 processing for best practices based on SAGE II**
- **Determine root cause of aerosol extinction coefficient low bias in 500-700 nm range**
  - Leading candidate is 1-2% overestimate of ozone.
- **Examine product's sensitivity to increased aerosol loading (HTHH)**
- **Bridging current climate observing system to future sensors**
  - Especially ozone and water vapor
- **Introduce research and new products**
- **Continue routine data collection and public distribution**



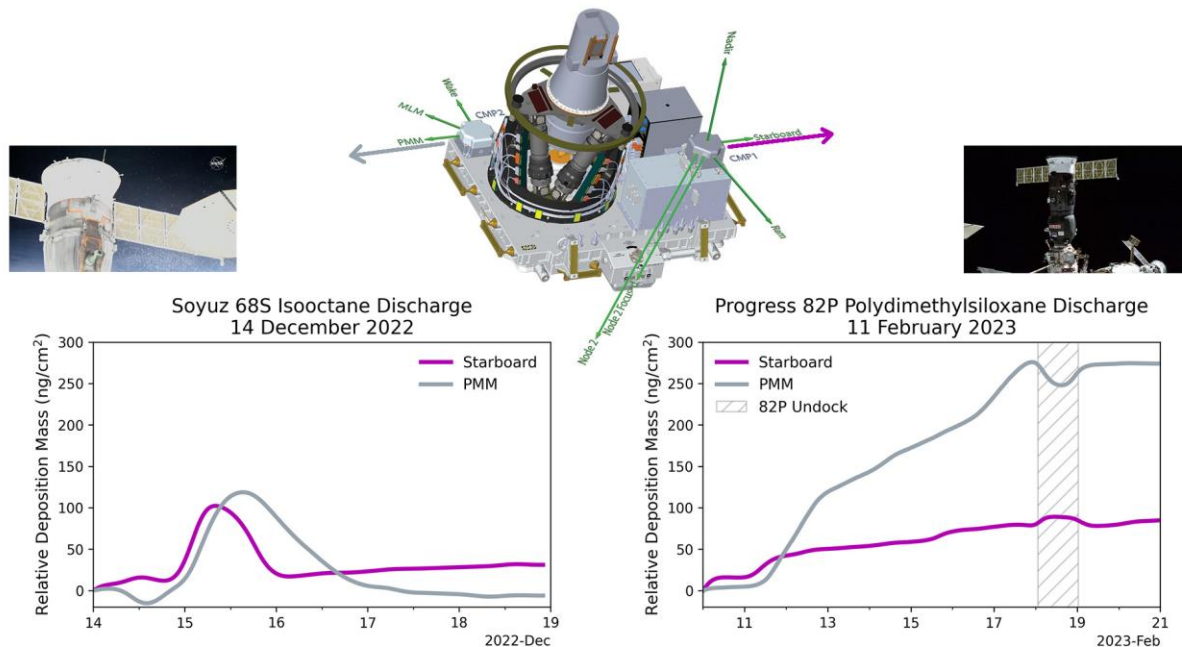
# Contamination Monitoring Improves Operations for ISS External Payloads



- SAGE III CMPs are enabling long-term monitoring of the ISS molecular contamination environment.
- ISS has used SAGE III contamination measurements to update/validate their analytical models for line-of-sight molecular transport of materials outgassing, along with amend models to include dispersal.
- SAGE III measurements have changed the paradigm for how contaminants move around the ISS. Line-of-sight to the contaminant source is not required to be impacted.

➤ The phased appearance of contaminant detection on sensors around the SAGE III payload during major leak events dramatically demonstrate that redistribution of contaminant fluence occurs, likely primarily because of scattering from ISS surfaces and secondarily from radiative interactions.

June 20, 2023





# Mission Update



- **The payload is healthy, collecting routine science**
- **SAGE III OPS normal command operations**
  - Efficiencies learned over the past three challenging years, but ISS is a very dynamic platform requiring more commanding to maintain the high efficiency of data collection
- **CMP MLM sensor has resumed operating – suspect workmanship sensitivity to mechanical disturbances**
- **DMP gyro still operating with two most important axes**
  - DMP team analysis shows negligible impact on recently implemented DMP attitude correction in science processing (v5.3)
- **Research science/engineering support contract transition – June 1:**
  - Increased contract costs
  - Working with contractor to retain skills/knowledge



# Questions: Updated Products



- **Q: Provide more details about what data product(s), including research products, will be included for the 2nd revision?**
- **A: The intent is to include improvements from all the proposed work. The pace of the improvements will be largely dictated by the approved funding level. The 'in-guide' scenario will make achieving all the goals over the next 3 years near impossible. Major improvements may cause us to update the public products earlier than planned so that science community can make use of them earlier rather than later.**
- **Improvements, in priority order:**
  - **Aerosol Biases – Significantly reduce/eliminate; most likely link with ozone retrieval**
  - **H<sub>2</sub>O Sensitivity – Reduced aerosol interference; reduce noise**
  - **NO<sub>2</sub> Biases – Improved spectroscopy**
  - **Homogeneity Assumption – Incorporate dependence in retrieval (NO<sub>2</sub> most likely candidate)**
  - **Mesospheric Ozone – Improve stray light correction and modeling for strong absorption across channel**
  - **Lunar Altitude registration – more robust**
  - **Lunar NO<sub>2</sub>/NO<sub>3</sub> – Reduce noise; improved spectroscopy (based on solar experience)**





# Research Products

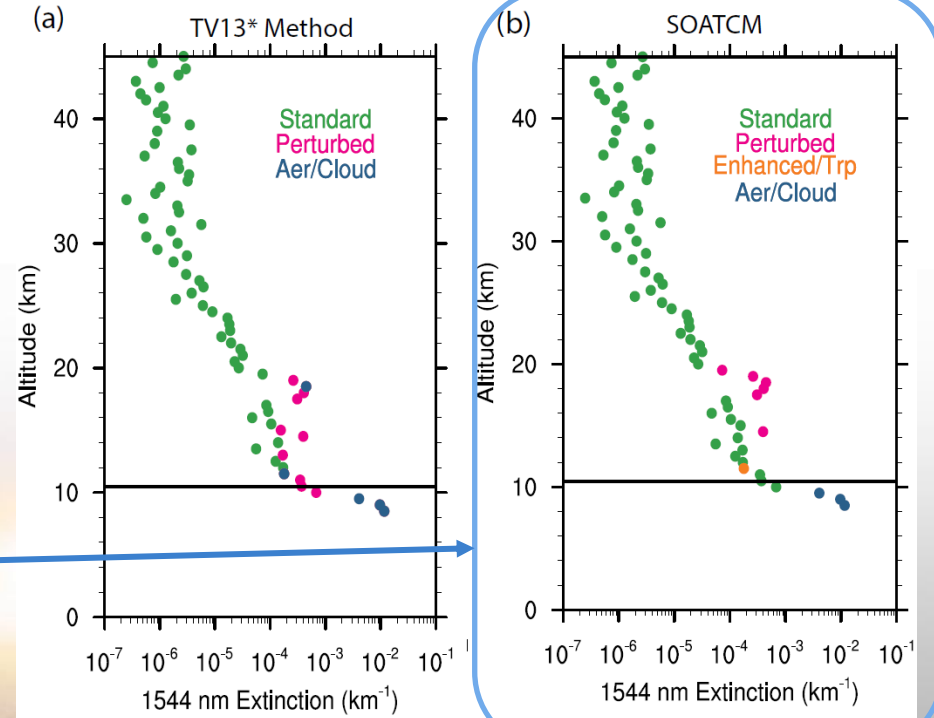


- **Birthing research products like the temperature/pressure profiles derived from oxygen-A band absorption will not be tied to the 2<sup>nd</sup> revision and can be released independently.**
- **SAGE III/M3M mission not successful - caused by latent issues in the instrument.**
- **Those were remediated in the SAGE III/ISS version and the results are greatly improved over the previous mission.**
  - Temperature profiles look very good but there is a significant pressure bias (maybe caused by the representation of the instrument in the forward model). Again, the timing of releasing new products is impacted by the level of staffing enabled by funding.
- **The limb scatter level L1b requires more work on the area of stray light correction in order to feel comfortable widely distributing (progress to date relied on summer interns and excellent they have been).**
  - As mentioned in the ROSES call for the next SAGE III/ISS science team (due Nov. 3, 2023) data is available on request for those wishing to prepare proposals.

# New Products -1

- It was not mentioned in the proposal, but the mission is planning to add a new product to the monthly release that should help the user screen the aerosol extinction profiles for cases contaminated by clouds.
- This utilizes an algorithm developed by [Kovilakam et al. \(2023\)](#) to improve the cloud clearing in the Global Satellite Stratospheric Aerosol Climatology (GloSSAC). The hope is to have this included early CY24.

2017092759SS, Lat: 49.30, Lon:-92.37, Canadian Wildfire

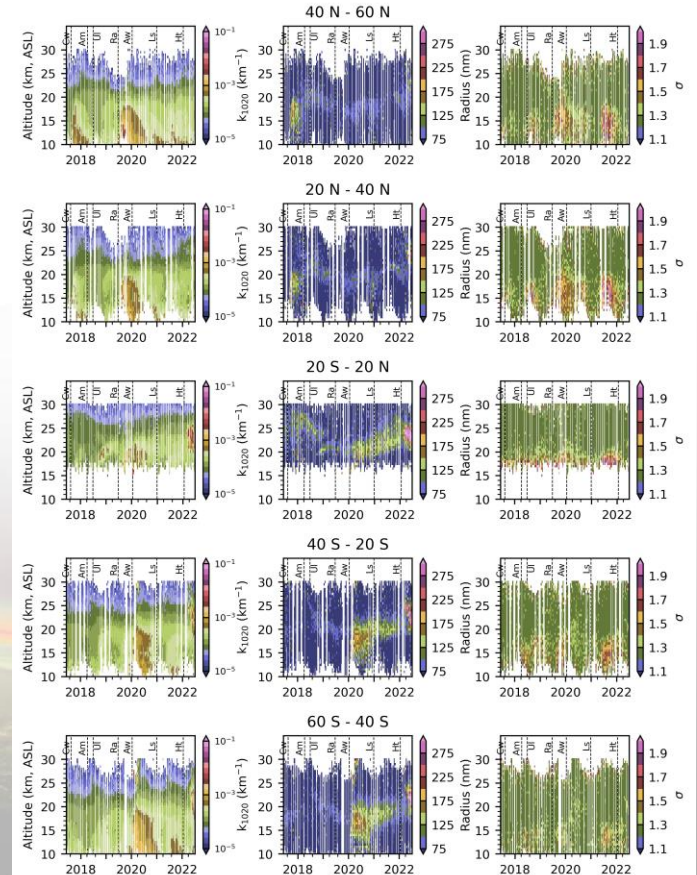


Courtesy M. Kovilakam



# New Products - 2

- Implementation Knepp et al. (2024) algorithm for particle size distribution parameters
- Plan is to incorporate this into the routine processing, similar to what was done for the aerosol/cloud flag, and include in a future version of the Level 2 solar products.
- In the meantime, Knepp is processing separately and making data products available via ASDC as part of the above publication



Courtesy T. Knepp





# Panel Summary



## NASA 2023 Earth Science Senior Review Panel Summary

Mission	Science Merit		Relevance		Standard Data Products		Overall Score		Science Findings
	Mean	Median	Mean	Median	Mean	Median	Mean	Median	
SAGE-III	4.4	4.5	4.5	4.5	4.4	4.5	4.4	4.5	Excellent /Very Good

Science scores are on a 1-5 scale, with 1 being the lowest ranking of “Poor” and 5 being the highest ranking of “Excellent.”

## NASA 2023 Earth Science Senior Review Extension Findings Summary

Mission	National Interests	Technical Performance	Cost Risk	Science Overall Findings	Mission Extension FY24-26	Mission Extension FY27-29
SAGE-III	Some	Excellent	Med. Low	Excellent/Very Good	Continue	Continue

**Review Panel commented that National Interests Panel lacked familiarity with the importance of ozone layer observations, i.e. Clean Air Act, Montreal Protocol.**

- *SAGE III can provide measurements with high accuracy and long-term stability compared to other satellites using nadir viewing, limb scattering, or emission techniques. Data from SAGE III are suitable for monitoring long-term trends in stratospheric composition.*
- *...advantage of SAGE III is it implicitly measures aerosol extinction coefficients at multiple wavelengths while other satellite instruments with limited wavelengths need to make assumptions of the aerosol properties (e.g., particle size distribution) in order to convert their native measurement to an extinction product.*
- *The extension of the SAGE III/ISS mission will enable the continuation of the climate data record for ozone, aerosols as well as water vapor.*
- *It will also help to improve retrievals from other instruments and bridge future missions. The overall scientific merit of the mission is excellent/very good. It is highly relevant to NASA Science Goals and the 2017 Decadal Survey.*
- *The Panel strongly supports the extension of SAGE-III for 2024-2026 with the in-guide budget. The project should succeed even though the budget is somewhat tight.*



- *Due to budget reduction, the SAGE III mission decided to defund the external validation effort in coordination with NOAA and NIWA. The review panel suggests the mission team to continue the coordination of validation efforts/activities through budget reallocation or ROSES funding.*
- *The review panel was concerned that so many important matters such as providing Quicklook data and assessing the effects of excess stratospheric  $H_2O$  and aerosols from the HTHH volcanic eruption on the accuracy of the  $O_3$  retrieval are not planned for the in-guide budget. Given the amount of time SAGE III has been on ISS, collecting excellent data, it had been thought that perhaps some greater efficiency of operations could have occurred, such that these matters could be addressed in some manner under the in-guideline budget.*



# Summary



- **SAGE uniquely provides geophysical reference standards for vertically resolved stratospheric concentrations of ozone, water vapor, nitrogen dioxide, and multi-wavelength aerosol extinction coefficient.**
- **SAGE III/ISS datasets have matured notably and are widely used for reference, science investigations (synergistically with other datasets and/or models) and trend studies.**
- **Mission understands the path to algorithm advancements, sensitivity studies & research products to enhance existing usages and fuel new applications of SAGE III/ISS data.**
- **SAGE III/ISS is in excellent position to extend the uniquely valuable science records throughout this decade, improve their quality and bridge to future missions.**
- **The risks and reduction in skilled expertise associated with the in-guide budget will have the following negative impacts to the mission science and dataset:**
  - **Science: Algorithm sensitivity studies and algorithm improvements severely impeded; Reduced data validation & no coordination of community ground-based correlative measurements**
  - **Operations: Loss of science data acquisition - Delayed response time: anomaly recovery; changes to ISS attitude and visiting vehicle schedule; data recovery from data download operation (loss of science and engineering data) - Data collection efficiency dropping from 83% to 75%**





# Backup





# Data Products



Profile Data Product	Status*	Units	Vertical Range (km)	Mid/Lower Stratospheric Precision (%)	Product Residence
<b>Transmission</b> Slant Path Transmission	Provisional	None	0–100	0.05	Level 1B Transmission
<b>Aerosol (9 Wavelengths)</b> Extinction Coefficient	Validated Stage 1	km <sup>-1</sup>	0–45	8	Level 2 Solar
<b>Ozone (MLR)</b> Concentration	Validated Stage 2	cm <sup>-3</sup>	0–70	5	Level 2 Solar
<b>Ozone (AO3)</b> Concentration	Validated State 2	cm <sup>-3</sup>	0–70	5	Level 2 Solar
<b>Ozone (Mesospheric)</b> Concentration	Provisional	cm <sup>-3</sup>	50–100	15	Level 2 Solar
<b>Nitrogen Dioxide</b> Concentration	Validated Stage 2	cm <sup>-3</sup>	0–70	15	Level 2 Solar
<b>Water Vapor</b> Concentration	Validated Stage 2	cm <sup>-3</sup>	0–70	20	Level 2 Solar
<b>Ozone</b> Concentration	Validated Stage 1	cm <sup>-3</sup>	0–70	5	Level 2 Lunar
<b>Nitrogen Dioxide</b> Concentration	Provisional	cm <sup>-3</sup>	0–70	15	Level 2 Lunar
<b>Nitrogen Trioxide</b> Concentration	Provisional	cm <sup>-3</sup>	0–70	15	Level 2 Lunar

## \*RELEASE STATUS DEFINITIONS

**Validated Stage 2** - Product uncertainty is estimated over a significant set of locations/time periods by comparison with suitable reference data. Results are published in the peer-reviewed literature.

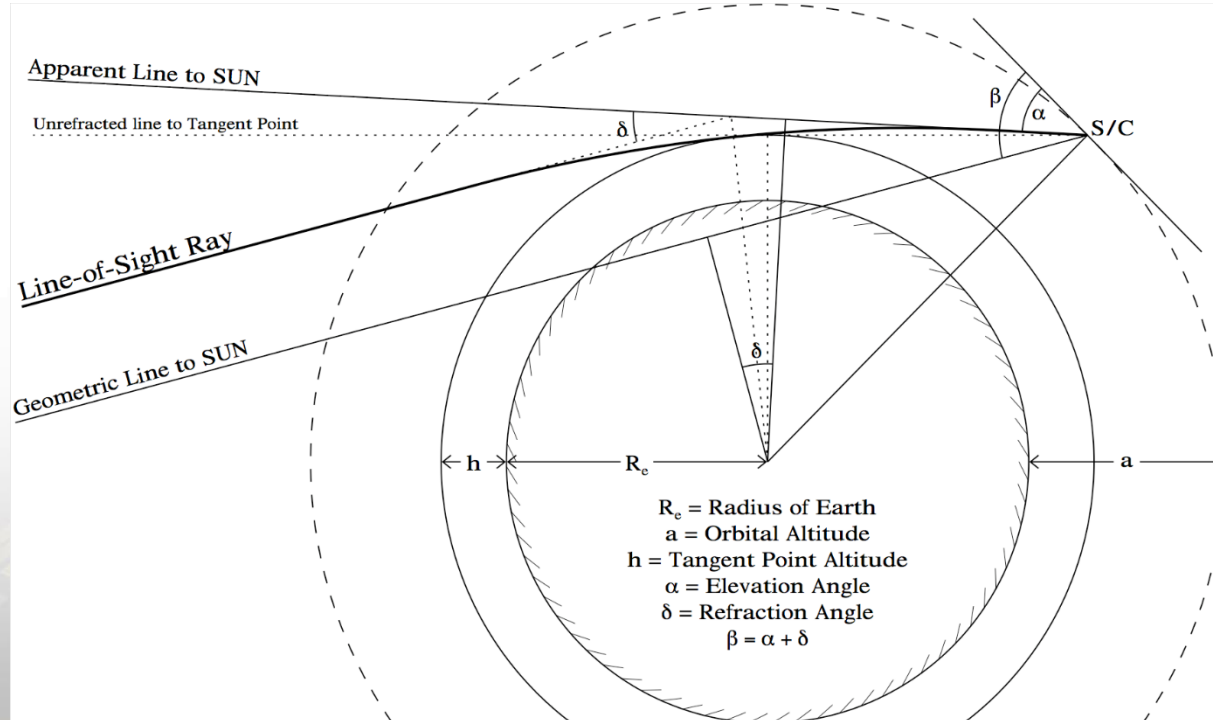
**Validated Stage 1** - Product uncertainty is estimated using a small number of independent measurements obtained from suitable reference data.

**Provisional** - These data are partially validated and improvements are continuing; quality may not be optimal since validation and quality assurance are ongoing.

**Research** - Suitable for validation, potentially usable for science and publications. Users cautioned.

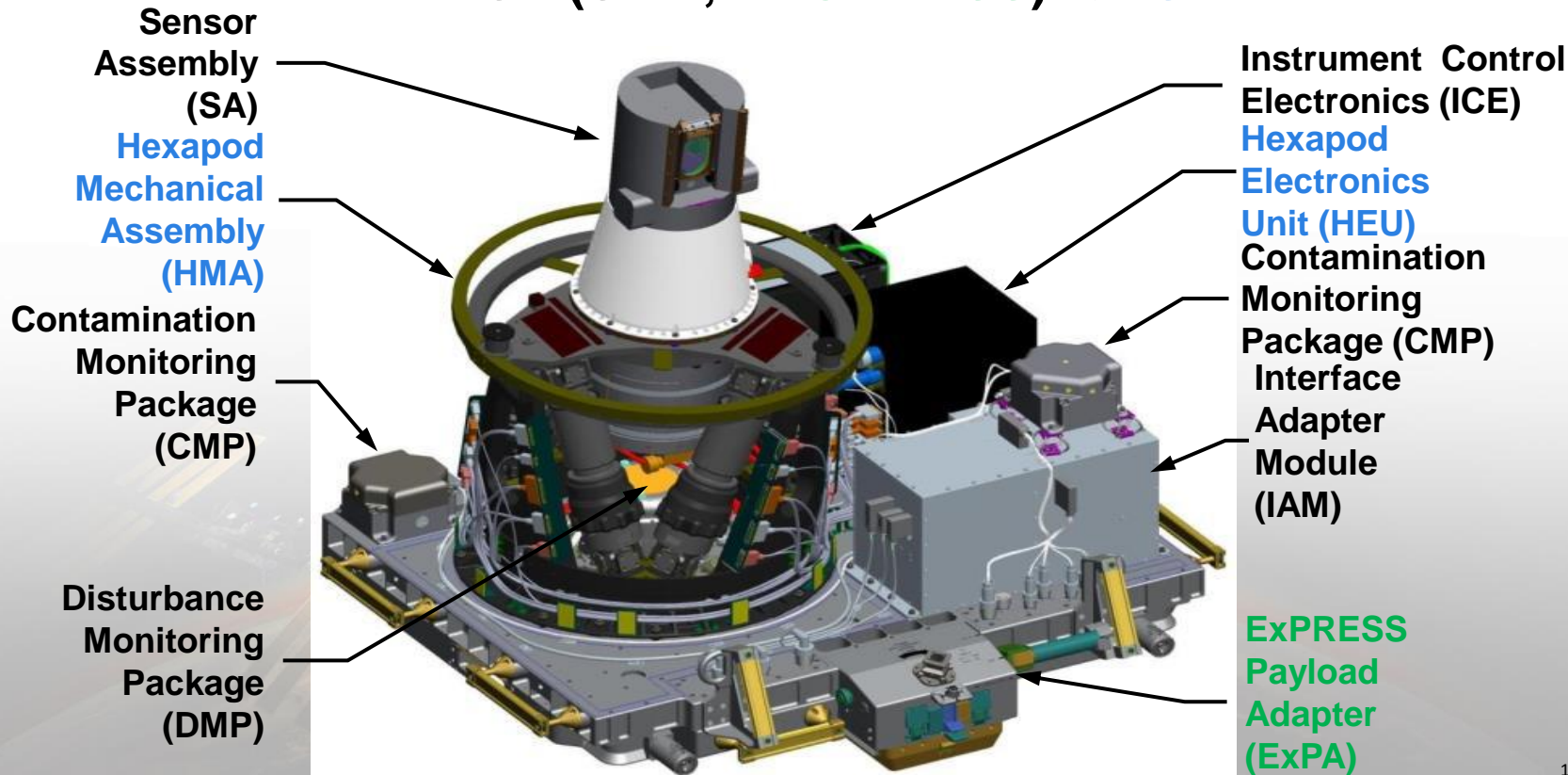
**Beta** - Products intended to enable users to gain familiarity with the parameters and the data. Comment to the SAGE III team is appreciated.

# Occultation Geometry



# SAGE III/ISS Integrated Payload (IP)

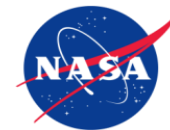
## ➤ Collaborative effort: NASA (SMD, **HEOMD-ISS**) & **ESA**







# Stratospheric Aerosol and Gas Experiment/International Space Station (SAGE III/ISS)

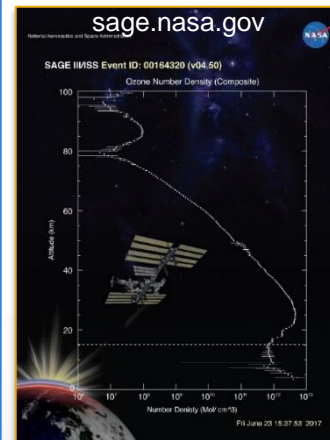


## Science Objectives:

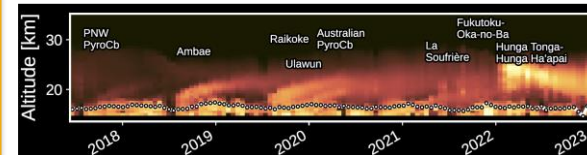
- Monitor the vertical distribution of aerosols, ozone, water vapor and other trace gases in Earth's stratosphere and troposphere to enhance understanding of ozone recovery and climate change processes in the upper atmosphere
- SAGE III/ISS will provide data necessary to:
  - Assess the state of the recovery in the distribution of ozone
  - Extend the stratospheric aerosol measurement record needed by both Climate models and Ozone models
  - Gain further insight into key processes contributing to ozone and aerosol variability

## Mission Approach:

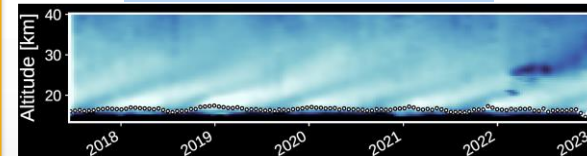
- Mid-inclined orbit w/ monthly coverage of tropics and mid-latitudes
- Launch Feb. 19, 2017 (CRS-10); Phase E start July 1, 2017
- Primary mission 3yr; manifested on ISS through 2030
- Resume flight project w/core hardware - SAGE III instrument & Hexapod
- Update payload for current/future ISS configuration (MLM)
- Augment payload for improved knowledge of ISS environment



## Aerosol Extinction Coefficient



## Water Vapor Mixing Ratio



## Mission Team:

- **NASA Langley** - Science; Project Management; System Engineering and Mission Design; SMA; I&T; Launch Support; Mission Operations; Science Data Processing and Delivery
- **NASA Johnson & ISS Program** - System Engineering Support, Hexapod Pointing System and ISS mounting adaptors, ISS Mounting Location, Launch Processing and Access to Space, Infrastructure and Telemetry Data
- **European Space Agency & TASI** - Hexapod Pointing System and Sustaining Engineering